

1

5

1

10

20

25

10

15

25

1
5
10
15
20
25

15
20
25

1 increase in capacity as described above, however, if the
channel spacing is decreased taking the bandwidth into
consideration and optical signals are set in the
proximity of a zero dispersion wavelength of the optical
5 fiber taking the chromatic dispersion into
consideration, an influence of a non-linear effect of
the optical fiber, particularly of four wave mixing
(hereinafter referred to as FWM), becomes significant,
and there is a subject to be solved in that the
10 transmission may be disabled by crosstalk from another
channel by such FWM. A similar subject resides in
another case wherein wavelength multiplex transmission
must be performed in a band in the proximity of the zero
dispersion wavelength in order to achieve, for example,
15 upgrading of an existing transmission line.

Meanwhile, as a factor of degradation of the
transmission characteristic in the optical amplifier
multi-repeater WDM method which particularly makes use
of a band in the proximity of a zero dispersion
20 wavelength of an optical fiber, crosstalk by FWM
mentioned above is pointed out. The occurrence
efficiency of such FWM depends upon the relationship
between the zero dispersion wavelength of the optical
fiber transmission line and the arrangement of channels.

25 Three characteristics including 1. a zero
dispersion wavelength, 2. a deviation in zero dispersion
wavelength and 3. a dispersion slope (second-order

SECRET 000000

1 dispersion) are listed as required characteristics for
an optical fiber in the WDM method. Those
characteristics are closely related to five factors
including a. a wavelength multiplexing signal bandwidth.
5 b. a gain bandwidth of the EDFA among various optical
amplifiers. c. a guard band for suppressing FWM to which
the present invention is directed, d. a limitation
bandwidth by an SPM-GVD effect, and e. presence or
absence of an inserted optical dispersion compensator.

10 By the way, as factors which restrict an
increase in distance and an increase in speed of an
optical communication system, there are limitation of
the loss by an optical fiber loss and bandwidth
limitation by chromatic dispersion. The loss limitation
15 has been almost solved by realization of EDFAs, and it
is possible to build up a very long-haul optical
communication system for several thousands km or more.

20 However, the repeater span in a multi-repeater optical amplification system is restricted principally by two factors including 1. optical SNR (signal to noise ratio) degradation caused by accumulation of ASE (spontaneous emission) from optical amplifier-repeaters, and 2. waveform degradation by an SPM-GVD effect caused by a Kerr effect.

25 It is already known that, of the two factors, the waveform degradation by an SPD-GVD effect can be compensated for using an optical dispersion compensator.

1 having a dispersion value of the opposite positive or
negative sign to that of the optical fiber transmission
line, and the waveform degradation by an SPM-GVD effect
and a dispersion compensation effect can be simulated
5 readily by solving a non-linear Schroedinger equation
using the split-step Fourier method.

866750-60608000
10 An optical dispersion compensator used for the
object described above is required to cope with a
dispersion amount of an optical fiber of a corresponding
repeater section and to allow reduction of the number of
steps and of the time necessary to realize an optimum
dispersion compensation amount and reduction of the
cost. Further, the optical dispersion compensation
technique is important not only for a 1.55 μm dispersion
15 shifted fiber (hereinafter referred to as DSF)
transmission line network being laid at present but also
for a long-haul, very high-speed optical communication
system and an optical communication system of the WDM
(FDM) method which make use of an existing 1.3 μm zero
20 dispersion single mode fiber (hereinafter referred to as
SMF) transmission line network.

25 In a very long-haul optical communication system
for several thousands km or more, it is considered
desirable to use the zero dispersion wavelength λ_0 of
the optical fiber transmission line in order to prevent
the dispersion penalty and to use the ordinary
dispersion region (dispersion value $D < 0$) of the

10

15

25

10

15

20

25

1 to the characteristics, is made clear to allow
establishment of channel arrangement of and transmission
line designing for signal light by an optical amplifier
multi-repeater WDM method.

5 It is a further object of the present invention
to provide an optical dispersion compensation method by
which waveform degradation by an SPM-GVD effect can be
compensated for readily without designing or producing
optical dispersion compensators suitable for individual
10 transmission lines and dispersion compensation can be
performed effectively even when the optical power is not
so high that SPM (self phase modulation) does not take
place very much but only waveform degradation is caused
by chromatic dispersion (GVD), thereby to reduce the
15 number of steps and the time required to build up an
optical communication system and to achieve reduction of
the cost.

In order to attain the objects described above,
according to an aspect of the present invention, there
20 is provided an optical wavelength multiplex transmission
method for multiplexing signal light waves of a
plurality of channels having different wavelengths and
transmitting the multiplexed signal light using an
optical fiber, wherein a four wave mixing suppressing
25 guard band of a predetermined bandwidth including a
zero-dispersion wavelength of the optical fiber is set,
and the signal light waves of the plurality of channels

60603060

1 to be multiplexed are arranged on one of a shorter wavelength side and a longer wavelength side outside the guard band.

In the optical wavelength multiplex transmission method, when signal light waves of a plurality of channels having different wavelengths are multiplexed and transmitted using an optical fiber, since the signal light waves of the plurality of channels to be multiplexed are arranged on one of the shorter wavelength side and the longer wavelength side outside the four wave mixing suppressing guard band of the predetermined bandwidth including the zero-dispersion wavelength of the optical fiber, otherwise possible four wave mixing is suppressed, and consequently, an influence from another channel by crosstalk is suppressed.

According to another aspect of the present invention, there is provided an optical wavelength multiplex transmission method for multiplexing signal light waves of a plurality of channels having different wavelengths and transmitting the multiplexed signal light using an optical fiber, wherein a four wave mixing suppressing guard band of a predetermined bandwidth including a zero-dispersion wavelength of the optical fiber is set, and the signal light waves of the plurality of channels to be multiplexed are arranged on the opposite sides of a shorter wavelength side and a

1 longer wavelength side outside the guard band.

5 In the optical wavelength multiplex transmission method, since signal light waves of a plurality of channels to be multiplexed are arranged on the opposite sides of the shorter wavelength side and the longer wavelength side outside the four wave mixing suppressing guard band, otherwise possible four wave mixing is suppressed, and consequently, an influence from another channel by crosstalk is suppressed and efficient utilization of the band can be achieved simultaneously.

10 The bandwidths of the guard bands may be set in an asymmetrical relationship on the shorter wavelength side and the longer wavelength side with respect to the zero-dispersion wavelength of the optical fiber. In this instance, the channel spacings between adjacent ones of the signal light waves of the plurality of channels may be set different on the shorter wavelength side and the longer wavelength side outside the guard band. Due to the channel spacings thus set, four wave mixing light produced between a signal light wave on the shorter wavelength side and another signal light wave on the longer wavelength side is prevented from coinciding with any of the wavelengths of the signal light waves.

15 Alternatively, the channel spacings between adjacent ones of the signal light waves of the plurality of channels on each of the shorter wavelength side and the longer wavelength side outside the guard band may be

set to an integral number of times a constant. Due to the channel spacings thus set, in addition to the advantage that an influence from another channel by crosstalk is suppressed, the channels on the shorter wavelength side and the longer wavelength side outside the guard band can be controlled using Fabry-Perot interferometers of a same characteristic. In this instance, preferably the channel spacings between the channels of the signal light waves of the plurality of channels on the opposite sides of the guard band are set to the integral number of times the constant. Due to the channel spacings thus set, the channels on the opposite sides of the shorter wavelength side and the longer wavelength side outside the guard band can be controlled simultaneously using a single Fabry-Perot interferometer of a same characteristic. Or else, the signal light waves of the channels may be arranged such that the signal light waves of no pair or only one pair of ones of the channels have dispersion values which have an equal absolute value. The arrangement further suppresses four wave mixing so that an influence from another channel by crosstalk can be further suppressed.

25. With the optical wavelength multiplex transmission methods described above, the following effects or advantages can be anticipated.

First, an influence of four wave mixing can be suppressed and the band can be utilized efficiently by

arranging signal light waves efficiently, an optical communication system of a large capacity can be realized while maintaining high transmission quality.

Second, even when a zero-dispersion wavelength is positioned within a band of an optical amplifier or within a band of an optical part, signal light waves can be arranged efficiently and compactly while suppressing an effect of four wave mixing within the limited band.

Third, Since the channel spacings on the transmission side can be controlled by means of a single or a pair of Fabry-Perot interferometers and an interferometer of the same characteristic to that of the interferometers on the transmission side can be used also on the reception side, control on the transmission side can be simplified and selective reception is facilitated.

According to a further aspect of the present invention, there is provided an optical wavelength multiplex transmission method for multiplexing signal light waves of a plurality of channels having different wavelengths and transmitting the multiplexed signal light using an optical fiber, wherein, taking a zero-dispersion wavelength λ_0 of the optical fiber and a zero-dispersion wavelength deviation range $\pm\Delta\lambda_0$ of the optical fiber in its longitudinal direction into consideration, the signal light waves of the plurality of channels to be multiplexed are arranged on a shorter

wavelength side than a shorter wavelength end $\lambda_0 - \Delta\lambda_0$ of the zero-dispersion wavelength deviation range of the optical fiber.

In the optical wavelength multiplex transmission method, when signal light waves of a plurality of channels having different wavelengths are multiplexed and transmitted using an optical fiber, since the signal light waves of the plurality of channels to be multiplexed are arranged on the shorter wavelength side than the shorter wavelength end $\lambda_0 - \Delta\lambda_0$ of the zero-dispersion wavelength deviation range of the optical fiber, the zero-dispersion wavelength deviation in the longitudinal direction of the optical fiber is taken into consideration and controlled on the shorter wavelength side of the zero-dispersion wavelength.

A four wave mixing suppressing guard band $\Delta\lambda_g$ may be provided on the shorter wavelength side than the shorter wavelength end $\lambda_0 - \Delta\lambda_0$ of the zero-dispersion wavelength deviation range of the optical fiber, and the signal light waves of the plurality of channels may be arranged on a shorter wavelength side than a wavelength $\lambda_0 - \Delta\lambda_0 - \Delta\lambda_g$. In this instance, since the signal light wave of the plurality of channels are arranged on the shorter wavelength side than the wavelength $\lambda_0 - \Delta\lambda_0 - \Delta\lambda_g$ taking the four wave mixing suppressing guard band $\Delta\lambda_g$ taken into consideration, the zero-dispersion wavelength deviation in the longitudinal direction of

1 the optical fiber is taken into consideration and controlled on the shorter wavelength side of the zero-dispersion wavelength, and simultaneously, an influence from another channel by crosstalk is suppressed.

5 According to a still further aspect of the present invention, there is provided an optical wavelength multiplex transmission method for multiplexing signal light waves of a plurality of channels having different wavelengths and transmitting the multiplexed signal light using an optical fiber, wherein, taking a zero-dispersion wavelength λ_0 of the optical fiber and a zero-dispersion wavelength deviation range $\pm\Delta\lambda_0$ of the optical fiber in its longitudinal direction into consideration, the signal light waves of the plurality of channels to be multiplexed are arranged on a longer wavelength side than a longer wavelength end $\lambda_0 + \Delta\lambda_0$ of the zero-dispersion wavelength deviation range of the optical fiber.

In the optical wavelength multiplex transmission method, when signal light waves of a plurality of channels having different wavelengths are multiplexed and transmitted using an optical fiber, since the signal light waves of the plurality of channels to be multiplexed are arranged on the longer wavelength side than the longer wavelength end $\lambda_0 + \Delta\lambda_0$ of the zero-dispersion wavelength deviation range of the optical fiber, the zero-dispersion wavelength deviation in the

longitudinal direction of the optical fiber is taken into consideration and controlled on the longer wavelength side of the zero-dispersion wavelength.

A four wave mixing suppressing guard band $\Delta\lambda_g$ may be provided on the longer wavelength side than the longer wavelength end $\lambda_0 + \Delta\lambda_0$ of the zero-dispersion wavelength deviation range of the optical fiber, and the signal light waves of the plurality of channels may be arranged on a longer wavelength side than a wavelength $\lambda_0 + \Delta\lambda_0 + \Delta\lambda_g$. Due to the provision of the four wave mixing suppressing guard band $\Delta\lambda_g$ and the arrangement of the signal light waves, the zero-dispersion wavelength deviation in the longitudinal direction of the optical fiber is taken into consideration and controlled on the longer wavelength side of the zero-dispersion wavelength, and simultaneously, an influence of another channel by crosstalk is suppressed.

The signal light waves of the plurality of channels may be arranged within a transmissible band defined by an allowable dispersion value determined from a synergetic effect of self phase modulation and group velocity dispersion in the optical fiber. Where the signal light waves are arranged in this manner, they can be arranged taking wavelength degradation by an SPM-GVD effect into consideration. Further, although SPM does not take place very much and only waveform degradation by chromatic dispersion (GVD) occurs when the optical

1 power is not very high, the signal light arrangement can
be performed also taking such waveform degradation into
consideration.

5 The signal light waves of the plurality of
channels may be arranged outside the transmissible band
defined by the allowable dispersion value determined
from the synergetic effect of self phase modulation and
group velocity dispersion in the optical fiber, and the
zero dispersion wavelength λ_0 of the optical fiber may
10 be apparently shifted using an optical dispersion
compensator to apparently arrange the signal light waves
of the plurality of channels into the transmissible
band. Due to the arrangement of the signal light waves
and the shift of the zero dispersion wavelength λ_0 , the
15 signal light waves can be arranged taking waveform
degradation by an SPM-GVD effect into consideration.

20 The optical wavelength multiplex transmission
method may be constructed such that, taking a dispersion
compensation amount deviation range $\pm\delta\lambda_{DC}$ of the optical
dispersion compensator into consideration, a band $\Delta\lambda_{WDM}$
within which the signal light waves of the plurality of
channels are to be arranged is set expanding the same by
the dispersion compensation amount deviation range $\delta\lambda_{DC}$
on the opposite sides of the longer wavelength side and
the shorter wavelength side. Due to the band $\Delta\lambda_{WDM}$ thus
25 set, the signal light waves can be arranged taking the
dispersion compensation amount deviation of the optical

1 dispersion compensator into consideration.

The signal light waves of the plurality of channels may be arranged in a gain band of an optical amplifier connected to the optical fiber. Due to the arrangement of the signal light waves, the powers of the signal light waves can be made equal to each other and also the receive characteristics of the signal light waves can be made equal to each other.

A band $\Delta\lambda_{\text{DM}}$ within which the signal light waves of the plurality of channels are to be arranged may be set expanding the same in accordance with optical wavelength variations of the signal light waves of the plurality of channels. Due to the band $\Delta\lambda_{\text{DM}}$ thus set, the productivity of light sources of the signal light waves and the variation of each signal light wave by the wavelength control accuracy are taken into consideration.

With the optical wavelength multiplex transmission methods described above, the following effects or advantages can be anticipated.

First, in a wavelength division multiplexing method which makes use of a band in the proximity of the zero-dispersion wavelength λ_0 of the optical fiber, the signal light waves of the individual channels can be arranged without being influenced by four wave mixing, and simultaneously, required characteristics regarding the zero-dispersion wavelength λ_0 for an optical fiber

606750-60603060

5 Second, the zero-dispersion wavelength deviation
in the longitudinal direction of the optical fiber is
taken into consideration and controlled, and
simultaneously, an influence of four wave mixing is
suppressed so that an influence from another channel by
10 crosstalk is suppressed. Consequently, a high degree of
transmission accuracy can be maintained.

20 Fourth, where a signal light band is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the channels,
the variations of the signal light waves arising from
the productivity and/or the wavelength control accuracy
25 of light sources of the signal light waves such as
semiconductor lasers are taken into consideration, and
where an optical dispersion compensator is employed, by

1 setting the signal light band expanding the same by a
dispersion compensation amount deviation range on the
opposite sides of the shorter wavelength side and the
longer wavelength side, also the dispersion compensation
5 amount deviation of the optical dispersion compensator
is taken into consideration. Consequently, optical
transmission of higher reliability can be achieved.

According to a yet further aspect of the present
invention, there is provided an optical dispersion
10 compensation method for compensating for a dispersion
amount of an optical transmission system which includes
a transmitter, a repeater and a receiver and transmits
signal light from the transmitter to the receiver by way
of the repeater, comprising the steps of preparing in
15 advance two kinds of optical dispersion compensator
units having dispersion amounts having different
positive and negative signs, inserting the two kinds of
optical dispersion compensator units separately into the
optical transmission system, and selecting one of the
20 two kinds of optical dispersion compensator units which
provides a better transmission characteristic to the
optical transmission system and incorporating the
selected optical dispersion compensator unit into the
optical transmission system.

25 In the optical dispersion compensation method,
since two kinds of optical dispersion compensator units
having dispersion amounts having different positive and

366750-60000000

1 having dispersion amounts having different positive and
negative signs are prepared in advance and, when the
dispersion amount of an optical transmission system can
be measured, the dispersion amount is measured and then
5 one of the two kinds of optical dispersion compensator
units which has a dispersion value whose sign is
opposite to that of a thus measured dispersion value is
selected, the dispersion amount of the optical
transmission system can be compensated for further
10 reliably.

According to a yet further aspect of the present
invention, there is provided an optical dispersion
compensation method for compensating for a dispersion
amount of an optical transmission system which includes
15 a transmitter, a repeater and a receiver and transmits
signal light from the transmitter to the receiver by way
of the repeater, comprising the steps of preparing in
advance a plurality of kinds of optical dispersion
compensator units having different dispersion amounts
20 having different positive and negative signs,
selectively inserting the plurality of kinds of optical
dispersion compensator units into the optical
transmission system changing the installation number and
the combination of the optical dispersion compensator
25 units, and selecting an installation number and a
combination of the optical dispersion compensator units
from within the plurality of kinds of optical dispersion

336753 6060300

1 compensator units which provide a good transmission
characteristic to the optical transmission system and
incorporating the optical dispersion compensator units
of the selected installation number and combination into
5 the optical transmission system.

In the optical dispersion compensation method,
since a plurality of kinds of optical dispersion
compensator units having different dispersion amounts
having different positive and negative signs are
10 prepared in advance and selectively inserted into an
optical transmission system changing the installation
number and the combination of the optical dispersion
compensator units and then an installation number and a
combination of the optical dispersion compensator units
15 which provide a good transmission characteristic to the
optical transmission system are selected from within the
plurality of kinds of optical dispersion compensator
units, the dispersion amount of the optical transmission
system can be compensated for simply and optimally when
20 the zero-dispersion wavelength deviation is unknown or
the zero-dispersion wavelength and the wavelengths of
the signal light waves are displaced by great amounts
from each other.

According to a yet further aspect of the present
25 invention, there is provided an optical dispersion
compensation method for compensating for a dispersion
amount of an optical transmission system which includes

000000-000000

1 a transmitter, a repeater and a receiver and transmits
signal light from the transmitter to the receiver by way
of the repeater, comprising the steps of preparing in
advance a plurality of kinds of optical dispersion
5 compensator units having different dispersion amounts
having different positive and negative signs, measuring
a dispersion amount of the optical transmission system,
and selecting an installation number and a combination
of the optical dispersion compensator units from within
10 the plurality of kinds of optical dispersion compensator
units, with which dispersion values of the signal light
waves fall within a transmissible dispersion value
range, in accordance with a measured dispersion value
and incorporating the optical dispersion compensator
15 units of the selected installation number and
combination into the optical transmission system.

In the optical dispersion compensation method,
since a plurality of kinds of optical dispersion
compensator units having different dispersion amounts
20 having different positive and negative signs are
prepared in advance and, when the dispersion amount of
an optical transmission system can be measured, the
dispersion amount is measured and then an optimum
installation number and an optimum combination of such
25 optical dispersion compensator units are selected in
accordance with a thus measured dispersion amount, the
dispersion amount of the optical transmission system can

866T50 60608060

1 be compensated for so that it may fall within an allowable dispersion value range with certainty.

The optical dispersion compensator units may be additionally incorporated into at least one of the transmitter, the repeater and the receiver of the optical transmission system to incorporate the optical dispersion compensator units into the optical transmission system.

When the optical transmission system performs optical wavelength multiplex transmission to multiplex and transmit signal light waves of a plurality of channels having different wavelengths, the signal light waves may be demultiplexed for each one wave by wavelength demultiplexing and the optical dispersion compensator units may be provided for the individual channels of the signal light waves of the wavelengths in the optical transmission system, or the signal light waves may be demultiplexed for each plurality of waves and the optical dispersion compensator units may be provided for the individual channel groups each including a plurality of signal light waves in the optical transmission system, or else the optical dispersion compensator units may be provided for all of the signal light waves of the plurality of channels in the optical transmission system.

Each of the optical dispersion compensator units may be additionally provided with an optical amplifier.

for compensating for an optical loss of the optical dispersion compensator unit. Due to the additional provision of the optical amplifier, the optical loss of each optical dispersion compensator unit can be compensated for. In this instance, a pair of optical amplifiers may be additionally provided at a preceding stage and a next stage to each of the optical dispersion compensator units. Due to the additional provision of the optical amplifiers, the noise figure (hereinafter referred to as simply NF) of the optical amplifier at the preceding stage can be set low.

The optical dispersion compensator units may be constructed as a package wherein they are mounted on a circuit board so that the optical dispersion compensator units may be replaced or incorporated in units of a package. Due to the construction of the optical dispersion compensator units, the dispersion compensation amount can be varied readily.

According to a yet further aspect of the present invention, there is provided an optical dispersion compensation method for compensating for a dispersion amount of an optical transmission system which includes a transmitter, a repeater and a receiver and transmits signal light from the transmitter to the receiver by way of the repeater, comprising the steps of incorporating, in advance into at least one of the transmitter, the repeater and the receiver of the optical transmission

1 system. a plurality of kinds of optical dispersion
compensator units having different dispersion amounts
having different positive and negative signs in such a
connected condition as to allow switching of a selective
5 combination of the optical dispersion compensator units
by means of switching means, and operating the switching
means to select a suitable combination of the optical
dispersion compensator units from within the plurality
of types of optical dispersion compensator units and
10 incorporating the optical dispersion compensator units
of the selected combination into the optical
transmission system.

In the optical dispersion compensation method,
since a plurality of kinds of optical dispersion
15 compensator units having different dispersion amounts
having different positive and negative signs are
incorporated in advance in at least one of a
transmitter, a repeater and a receiver of an optical
transmission system in such a connected condition as to
20 allow switching of a selective combination of the
optical dispersion compensator units by means of
switching means, a suitable combination of the optical
dispersion compensator units can be selected from within
the plurality of types of optical dispersion compensator
25 units.

The switching means may be operated in response
to a control signal from the outside. In this instance,

15

20

25

5

10

15

20

25

FIG. 6 is a similar view but illustrating the arrangement of signal light waves of a plurality of channels according to an optical wavelength multiplex

1 transmission method of a third preferred embodiment of
the present invention:

FIG. 7 is a diagram illustrating operation of the third embodiment of the present invention:

5 FIG. 8 is a diagrammatic view illustrating the arrangement of signal light waves of a plurality of channels according to an optical wavelength multiplex transmission method of a fourth preferred embodiment of the present invention:

10 FIG. 9 is a similar view but illustrating the arrangement of signal light waves of a plurality of channels according to an optical wavelength multiplex transmission method of a fifth preferred embodiment of the present invention:

15 FIG. 10 is a similar view but illustrating the arrangement of signal light waves of a plurality of channels according to an optical wavelength multiplex transmission method of a sixth preferred embodiment of the present invention;

20 FIGS. 11 and 12 are diagrams illustrating
operation of the sixth embodiment of the present
invention;

FIG. 13 is a diagrammatic view illustrating the arrangement of signal light waves of a plurality of channels according to an optical wavelength multiplex transmission method of a seventh preferred embodiment of the present invention;

1

5

10

FIG. 17 is a diagram illustrating the

15

20

FIG. 20 is a graph illustrating the signal light wavelength dependency of the FWM occurrence efficiency;

FIG. 21 is a graph illustrating the relationship between the channel spacing and a guard band:

25

SECRET

[illegible][illegible]

SECRET

[illegible][illegible][illegible]

FIG. 29 is a block diagram showing a modification to the optical dispersion compensation system shown in FIG. 28:

FIG. 30 is a block diagram showing another modification to the optical dispersion compensation system shown in FIG. 28:

FIG. 31 is a block diagram showing an optical dispersion compensation system to which an optical dispersion compensation method of a twelfth preferred embodiment of the present invention is applied:

FIG. 32 is a block diagram showing a modification to the optical dispersion compensation system shown in FIG. 31:

FIG. 33 is a block diagram showing another modification to the optical dispersion compensation system shown in FIG. 31:

FIG. 34 is a block diagram showing an optical dispersion compensation system to which an optical dispersion compensation method of a thirteenth preferred embodiment of the present invention is applied:

FIG. 35 is a block diagram showing a modification to the optical dispersion compensation system shown in FIG. 34:

FIG. 36 is a block diagram showing another modification to the optical dispersion compensation system shown in FIG. 34:

FIG. 37 is a block diagram showing an optical

1 dispersion compensation system to which an optical
dispersion compensation method of a fourteenth preferred
embodiment of the present invention is applied:

5 FIGS. 38(a) and 38(b) are block diagrams showing
a modification to the optical dispersion compensation
system shown in FIG. 37:

FIG. 39 is a block diagram showing another
modification to the optical dispersion compensation
system shown in FIG. 37:

10 FIG. 40 is a schematic illustration showing an
exemplary construction of a package according to the
modified optical dispersion compensation system shown in
FIG. 39:

15 FIG. 41 is a block diagram showing an optical
dispersion compensation system to which an optical
dispersion compensation method of a fifteenth preferred
embodiment of the present invention is applied:

20 FIG. 42 is a block diagram showing an adaptation
of the optical dispersion compensation system shown in
FIG. 41; and

FIG. 43 is a block diagram showing another
adaptation to the optical dispersion compensation system
shown in FIG. 41.

25 DESCRIPTION OF THE PREFERRED EMBODIMENTS

A. First Embodiment

FIGS. 1 to 4 illustrate an optical wavelength

1 multiplex transmission method according to a first
preferred embodiment of the present invention.

5 First, an optical WDM distribution transmission
system to which the optical wavelength multiplex
transmission method of the present embodiment is applied
will be described. Referring to FIG. 2, the optical WDM
distribution transmission system shown includes a
transmission circuit 1 which multiplexes signals from a
plurality of channels into signal light waves having
10 different frequencies or wavelengths in a high density.

The transmission circuit 1 includes a laser
diode (LD-1 to LD-n) 1a provided for each of the
channels CH-1 to CH-n, and a wave combiner 1b for
receiving signal light waves from the laser diodes 1a of
15 the channels and multiplexing the received signal light
waves.

The optical WDM distribution transmission system
further includes an optical fiber 2 for transmitting
multiplexed signal light waves from the transmission
circuit 1, a distributor 3 for distributing a signal
20 from the optical fiber 2 among different channels, and a
reception circuit 4 provided for each of the channels
CH-i ($i = 1$ to n) for receiving signal light of a
frequency or wavelength allocated to the channel. Each
of the reception circuits 4 includes an optical filter
25 4a for extracting and outputting a corresponding signal
from multiplexed signal light, a control circuit 4b for

000000-051988

controlling the optical filter 4a. and a detector 4c for detecting signal light from the optical filter 4a.

By the way, FWM as a non-linear effect of the optical fiber 2 is a phenomenon which is produced by optical frequency mixing between different signal light waves having different frequencies or wavelengths from each other when the signal light waves are multiplexed and inputted to the optical fiber 2 using a band in the proximity of the zero-dispersion wavelength of the optical fiber 2. and makes a factor of crosstalk from another channel and degrades the signal transmission characteristic.

The FWM which is a non-linear effect of the optical fiber 2 has a most significant influence upon optical WDM (FDM) transmission which employs a band in the proximity of the zero-dispersion wavelength of the optical fiber 2. In order to give a more detailed description of the FWM, a system design which must be performed taking an influence of the FWM into consideration, particularly, the channel spacing, the channel arrangement and the input power, will be described below.

For example, when signal light waves of frequencies f_1 to f_n (wavelengths λ_1 to λ_n) are inputted, a fourth light wave of a frequency f_{ijk} (wavelength λ_{ijk} ; $i \neq k$, $j \neq k$) is generated from arbitrary three waves f_i , f_j and f_k (wavelengths λ_i , λ_j

RECEIVED

Meanwhile, the frequency f_{ijk} (wavelength λ_{ijk}) exhibits a high occurrence efficiency in the proximity of the zero-dispersion wavelength, and the efficiency is varied by the phase relationship among the frequencies f_i , f_j , f_k and f_{ijk} (wavelengths λ_i , λ_j , λ_k and λ_{ijk}), or the efficiency becomes higher as the phase inconsistency amount $\Delta\beta$, which will be hereinafter described, increases.

$$25 \quad P_{ijk} = \eta_{ijk} \cdot \{ (1.024\pi^8 \cdot \chi_{1111}^2 \cdot d^2) / n^4 \cdot \lambda^2 \cdot c^2 \} \cdot (L_{eff} / A_{eff})^2 \cdot P_i \cdot P_j \cdot P_k \cdot \exp(-\alpha L) \quad (2)$$

where η_{ijk} is the occurrence efficiency of the frequency

1 f_{ijk} (wavelength λ_{ijk}). χ_{ijk} is the third-order non-
linear susceptibility, d is the degeneracy coefficient
($d = 6$ when $i \neq j \neq k$, and $d = 3$ when $i = j \neq k$). n is
the refraction index of the core, λ is the signal
5 wavelength, c is the velocity of light, L_{eff} is the
effective optical fiber length given by the equation (3)
given below. A_{eff} is the effective core area ($= \pi W^2$, W
is the mode field diameter), α is the attenuation
coefficient of the optical fiber, and P_i , P_j and P_k are
10 the input powers of signal light waves of the
frequencies f_i , f_j and f_k (wavelengths λ_i , λ_j and λ_k),
respectively.

$$L_{eff} = (1 - \exp(-\alpha L)) / \alpha \quad (3)$$

where the occurrence efficiency η_{ijk} ($= \eta$) is given by
15 the following equation (4):

$$\eta = \alpha^2 \cdot [1 + 4 \exp(-\alpha L) \cdot \sin^2(\Delta\beta L/2)] / \{ [1 - \exp(-\alpha L)]^2 + (\alpha^2 + \Delta\beta^2) \} \quad (4)$$

where L is the optical fiber length, and $\Delta\beta$ is the phase
inconsistency amount. Further, if it is assumed that
20 the dispersion slope $dD/d\lambda$ of the optical fiber is
fixed with respect to the wavelength, the phase
inconsistency amount $\Delta\beta$ is given by the equation (5) or
(6) below:

a. In the case of $f_i \neq f_j \neq f_k$ ($\lambda_i \neq \lambda_j \neq \lambda_k$):

$$\Delta\beta = (\pi \lambda^4 / 3c^2) \cdot (dD/d\lambda) \cdot \{ (f_i + f_j - f_k - f_0)^3 - (f_i - f_0)^3 - (f_j - f_0)^3 + (f_k - f_0)^3 \} \quad (5)$$

b. In the case of $f_i = f_j \neq f_k$ ($\lambda_i = \lambda_j \neq \lambda_k$):

$$\Delta\beta = (\pi\lambda^4/c^2) \cdot (dD/d\lambda) \cdot 2 \cdot (f_i - f_0) \cdot (f_i - f_k)^2 \quad (6)$$

where D is the chromatic dispersion of the optical fiber, $dD/d\lambda$ is the chromatic dispersion of the second order of the optical fiber, and f_0 is the zero-dispersion optical frequency. It is to be noted that the equations (5) and (6) stand also where the frequencies f_i , f_j , f_k and f_0 are replaced by the wavelengths λ_i , λ_j , λ_k and λ_0 , respectively.

Where a plurality of channels are involved, combinations of i, j and k of FWM waves which appear at the positions of the frequency f_{ijk} (wavelength λ_{ijk}) are calculated, and optical powers P_{ijk} are individually calculated for them. Then, the sum total of the optical powers P_{ijk} makes an optical power of the FWM wave produced at the position of the frequency f_{ijk} (wavelength λ_{ijk}). Using the sum total of the optical powers, a crosstalk amount CR is calculated in accordance with the following equation (7):

$$CR = 10 \cdot \log \left(\frac{\text{sum total of all FWM optical powers appearing at positions of } f_{ijk}}{\text{signal optical power at positions of } f_{ijk}} \right) \quad (7)$$

The influence of FWM can be estimated using the equations (2) and (4) to (7), which allows designing of values of parameters of the system such as a channel spacing, a channel arrangement and an input power. In the description of action and effects of the first to

sixth embodiments of the invention given below, an estimated influence of FWM (refer to FIG. 3, 4, 7, 11 or 12) obtained in accordance with the equations given hereinabove will be used suitably.

As described hereinabove, in order to prevent waveform deterioration by dispersion of the optical fiber 2, it is necessary to make use of a band in the proximity of the zero-dispersion wavelength of the optical fiber and also to assure a channel spacing and a signal channel arrangement taking an influence of FWM, which appears significantly when the band is used for multiplexing, into consideration. To this end, in the optical wavelength multiplex transmission method according to the first embodiment of the present invention, signal light waves of different channels are arranged, for example, as illustrated in FIG. 1.

According to such a channel arrangement as illustrated in FIG. 1, an FWM suppressing guard band 5 of a fixed width ranging from a zero-dispersion wavelength λ_0 is provided, and signal light waves are disposed on the longer wavelength side 6 than the zero-dispersion wavelength λ_0 outside the guard band 5.

Due to the construction described above, in the optical wavelength multiplex transmission system to which the optical wavelength multiplex transmission method according to the first embodiment of the present invention is applied, signals from the different

channels are multiplexed in a high density as signal light waves of different frequencies or wavelengths from one another by the transmission circuit 1 and transmitted by way of the optical fiber 2.

The signal light waves transmitted by way of the optical fiber 2 are demultiplexed by the distributor 3 and inputted to the reception circuits 4 of the corresponding channels and detected as signal light waves of the frequencies or wavelengths corresponding to the input channels.

In this instance, where the system is constructed, for example, such that the number of channels of the transmission circuit 1 is 16 ($n = 16$); the channel spacing is 150 GHz; the length L of the optical fiber 2 is 90 km; and the optical input power P of each channel is +3 dBm, the results of calculation of crosstalk amounts of the channels are such as illustrated in FIG. 3. The parameters used for the calculation are $\chi_{1111} = 5.0 \times 10^{-15} \text{ cm}^3/\text{erg(esu)}$, $A_{eff} = 4.6 \times 10^{-11} \text{ m}^2$, $\alpha = 5.2958 \times 10^{-5} \text{ m}^{-1}$ (0.23 dB/km), and $dD/d\lambda = 0.065 \text{ ps}/(\text{km} \cdot \text{nm}^2)$.

In FIG. 3, such a representation as "0.0 ps/nm/km" indicates a value of dispersion at the channel 1 CH1. As the channel number (CH No.) increases, the dispersion value increases in accordance with the dispersion slope $dD/d\lambda$. From the result illustrated in FIG. 3, the crosstalk amounts at the channels CH2, CH3

1 and CH4 exhibit comparatively high values.

Results of calculation performed paying
attention to the channels CH2, CH3 and CH4 are
illustrated in FIG. 4. As seen from FIG. 4, in order to
5 suppress the crosstalk amount, for example, below 30 dB,
the dispersion value of the channel CH1 should be 0.64
ps/nm/km or more, and where, for example, $dD/d\lambda = 0.065$
ps/(km·nm²), the channel CH1 should be displaced
approximately 10 nm from the zero-dispersion wavelength
10 λ_0 . Accordingly, the guard band 5 should have a width
of 10 nm.

In this manner, according to the optical
wavelength multiplex transmission method of the first
embodiment, by arranging signal light waves of different
15 channels from the zero-dispersion wavelength λ_0 of the
optical fiber 2 with the guard band 5 interposed
therebetween, an influence of FWM can be suppressed and
an influence from another channel by crosstalk can be
suppressed. Further, since the band can be utilized
20 efficiently, an optical communication system of an
increased capacity can be realized while maintaining a
high degree of transmission accuracy.

It is to be noted that, while, in the present
embodiment, signal light waves are arranged on the
25 longer wavelength side 6 with respect to the zero-
dispersion wavelength λ_0 , they may alternatively be
arranged on a shorter wavelength side 7 with respect to

00000000-00000000

✓

B. Second Embodiment

5

10

20

25

1 waves can be arranged efficiently and compactly while
suppressing an effect of FWM in the limited band to
suppress an influence from another channel by crosstalk,
and accordingly, there is an advantage in that an
5 increase of the capacity of the system can be realized
while maintaining a high degree of transmission
accuracy.

C. Third Embodiment

Subsequently, an optical wavelength multiplex
10 transmission method according to a third preferred
embodiment of the present invention will be described.
FIG. 6 illustrates an arrangement of signal light waves
of a plurality of channels of the optical wavelength
multiplex transmission method, and FIG. 7 illustrates
15 operation according to the optical wavelength multiplex
transmission method. It is to be noted that also the
optical wavelength multiplex transmission method of the
third embodiment is applied to a system similar to the
optical WDM (FDM) distribution transmission system
20 described hereinabove with reference to FIG. 2, and
overlapping description of the same will be omitted
herein to avoid redundancy.

According to the optical wavelength multiplex
transmission method of the third embodiment, as shown in
25 FIG. 6, a pair of FWM suppressing guard bands 5 are
provided in an asymmetrical relationship on the shorter
wavelength side 7 and the longer wavelength side 6 with

09030909 051403

$$5 \quad 6 \quad (\Delta f') .$$

15 appear is displaced from the band of the signal light is desirably set within a range within which the width can be suppressed by the optical filter 4a on the reception side.

25 nm on the longer wavelength side 6. FWM light is produced between different channels. but production of FWM light is reduced within the bands of signal light

1

5

15

20

25

5

10

15

20

25

From such point of view, by setting the channel spacings on the shorter wavelength side 7 and the longer wavelength side 6 than the zero-dispersion wavelength λ_0 to integral numbers of times a constant (distance of one period of transmission peaks of optical interferometers or an integral number of times the distance), channels on the shorter wavelength side 7 and the longer wavelength side 6 can be controlled by one or two Fabry-Perot interferometers of the same characteristic. This similarly applies to the reception circuit 4. In particular, by setting the channel spacings to integral numbers of times a constant, an interferometer of the same characteristic can be used.

1 In this manner, with the optical wavelength
multiplex transmission method of the fourth embodiment,
since the channel spacings on the transmission side can
be controlled by means of a single or two Fabry-Perot
5 interferometers, there is an advantage in that the
control on the transmission side can be simplified.

This also applies to the reception side. In
particular, by setting the channel spacings to integral
numbers of times a constant, an interferometer having
10 the same characteristic as that of the interferometers
on the transmission side can be used. Consequently,
there is an advantage in that selective reception is
facilitated and the apparatus can be simplified.

It is to be noted that, in the present
15 embodiment, the channel spacing between adjacent
channels of signal light waves of a plurality of
channels can be set such that it may be different on the
shorter wavelength side 7 and the longer wavelength side
6 outside the guard bands 5.

20 E. Fifth Embodiment

Subsequently, an optical wavelength multiplex
transmission method according to a fifth preferred
embodiment of the present invention will be described.
FIG. 9 illustrates an arrangement of signal light waves
25 of a plurality of channels of the optical wavelength
multiplex transmission method. It is to be noted that
also the optical wavelength multiplex transmission

[illegible][illegible][illegible][illegible]

10
15
20

Subsequently, an optical wavelength multiplex transmission method according to a sixth preferred embodiment of the present invention will be described. FIG. 10 illustrates an arrangement of signal light waves of a plurality of channels of the optical wavelength multiplex transmission method, and FIGS. 11 and 12 illustrate operation of the same. It is to be noted that also the optical wavelength multiplex transmission method of the sixth embodiment is applied to a system similar to the optical WDM (FDM) distribution transmission system described hereinabove with reference to FIG. 2, and overlapping description of the same will be omitted herein to avoid redundancy.

In the optical wavelength multiplex transmission method of the sixth embodiment, different channels are arranged such that two or more channels may not overlap with each other, that is, one pair of channels or less may have an equal absolute value of a dispersion value when the channel arrangement is folded on itself at the

1

5

20

channels CH2 and CH15 overlap with each other and the channels CH5 and CH11 overlap with each other. In other words, the two pairs of channels have equal absolute

5

10

G. Seventh Embodiment

15

20

25

10 In the seventh and eighth embodiments described
below, a channel arrangement method according to the WDM
method when the factors described above are taken into
consideration will be described. Conversely speaking,
this can be regarded as a defining method between the
15 zero-dispersion wavelength of an optical fiber and the
deviation of the zero-dispersion wavelength in a
situation wherein the number of channels and the channel
spacing are decided.

In the following description, a limiting band by a. a wavelength multiplex signal band, b. a gain band of an EDFA, c. a guard band for suppression of FWM and d. an SPM-GVD effect, which are factors to limit the signal light band, will be described first, and then the relationship between a channel arrangement and characteristics required for an optical fiber will be described taking presence or absence of an inserted optical dispersion compensator into consideration.

•Limiting Factors

a. Wavelength Multiplex Signal Band

Where signal light of n waves is arranged at an equal wavelength spacing (channel spacing) $\Delta\lambda_s$, a wavelength multiplex signal light band $\Delta\lambda_{wpm}$ is given by $\Delta\lambda_s \times (n - 1)$. It is to be noted that, in the case of an equal wavelength spacing arrangement, FWM light in the signal light band is liable to become high while wavelength stabilization is facilitated as described hereinabove in the fourth and fifth embodiments.

b. EDFA Gain Band

In the case of optical transmission of the WDM method, in order to make the reception characteristic equal among different waves, the signal light power must be made equal among the different waves, and to this end, a frequency band in which the gain of the EDFA exhibits a flat characteristic must be used. For example, in FIG. 16, an example of an ASE spectrum after EDFAs are connected at four stages (the ASE spectrum distribution is substantially equal to the gain distribution of an EDFA) is illustrated, and in the EDFA technique at present, the range of 1.550 to 1.560 nm is a frequency band in which the gain is flat. Consequently, it is desirable to arrange signal light of all channels within the bandwidth ($\Delta\lambda_{EDFA} = 10$ nm).

It is to be noted that, as another frequency band than that described above, a frequency band in the

2025 RELEASE UNDER E.O. 14176

1.0 c. Guard Band for ~~FWM~~ Suppression

The wavelength λ_{ijk} satisfies the relationship of the equation (1) given hereinabove and causes crosstalk and degrades the transmission characteristic when signal light is present at the position. Particularly where the channel spacings are equal and

10 Generally, when the polarization conditions of
three signal light waves and the phases of the three
signal light waves at the input terminal of an optical
fiber, the FWM optical powers P_{ijk} and the production
efficiencies η_{ijk} are given by the equations (2) and (3)
15 and the equations (4) to (6) given hereinabove.

20 $\Delta\lambda_s = 1.2$ nm as shown, for example, in FIG. 17 and when
the dispersion value $D_{0\lambda 1}$ of the channel 1 is varied is
illustrated in FIG. 18. Parameters used for the
calculation are: $\lambda = 1.55$ μm , $\chi_{1111} = 5.0 \times 10^{-15}$ esu,
 $A_{eff} = 4.6 \times 10^{-11}$ m^2 , $\alpha = 5.3 \times 10^{-6}$ m^{-1} (0.23 dB/km).
25 $dD/d\lambda = 0.065$ ps/(km \cdot nm 2), $L = 90$ km, and $P_i = 0$ dBm/ch

As seen from FIG. 18, the number of combinations of FWM light waves overlapped with different channels

5
10
15
20
25

15

20

25

transmission line (optical fiber 2) for amplifying a
signal attenuated by line loss.

The regenerative repeater system further
includes a plurality of regenerative-repeaters 13
interposed substantially at a fixed distance L_{R-R}
greater than the distance $L_{in-line}$ between the in-line
repeaters 12 in the optical transmission line (optical
fiber 2). The regenerative-repeaters 13 are provided to
regenerate pulse signals from signal light in the
optical transmission line before the signal light is
degraded by an influence of noise relying upon the line
characteristic into a condition in which signals thereof
cannot be discriminated from one another, and have three
functions represented by words beginning with R
including reshaping, retiming and regenerating.
Therefore, such a regenerative-repeater is also called
3R repeater.

The regenerative repeater system further
includes a receiver 14 for demultiplexing signal light,
which has been multiplexed by the construction
(reception circuit 4) described hereinabove with
reference to FIG. 2 and converting the signal light
waves obtained by the demodulation into electric
signals.

In the present embodiment, the transmitter 11
and the receiver 14 are interconnected by way of the
optical fiber 2 with the plurality of in-line repeaters

1 12 and regenerative-repeaters 13 interposed in the
optical fiber 2 to construct the optical transmission
system or regenerative-repeater system 10 according to
the optical amplifier multi-repeater WDM method.

5 By the way, in the case of the optical
transmission system 10 of such a construction as
described above, the distance L_{R-R} between the
regenerative-repeaters 13 are restricted principally by
two factors including 1. optical signal to noise
10 degradation by ASE accumulation at the in-line repeaters
12 and 2. waveform degradation by an SPM-GVD effect
caused by a Kerr-effect in the optical fiber 2.

Simultaneously, the lower limit to the input power into
the optical fiber 2 is limited by the optical signal to
15 noise ratio while the upper limit is limited by the SPM-
GVD effect. It is to be noted that, for evaluation of
waveform degradation by an SPM-GVD effect, generally a
simulation which involves solution of a non-linear
Schroedinger equation using the split step Fourier
20 method is effective.

FIG. 19 illustrates an example of a relationship
between the input power to the optical fiber 2 and the
distance L_{R-R} between the regenerative-repeaters 13
when the transmission rate is 10 Gbps, the distance
25 $L_{in-line}$ between the in-line repeaters 12 is 70 km and
only one wave is transmitted. If it is assumed that the
variation of the optical output from each optical

1 amplifier (in-line repeater 12) is ± 2 dB, where an
allowable dispersion value D_{allow} is $D_{allow} = \pm 1$
ps/(nm·km), the maximum value of the distance L_{r-r}
between the regenerative-repeaters 13 is 280 km, and
5 where the allowable dispersion value D_{allow} is $D_{allow} =$
 ± 2 ps/(nm·km), the maximum value of the distance L_{r-r}
between the regenerative-repeaters 13 is 210 km. In
order to realize long-haul transmission, it is necessary
to set the allowable dispersion value low and set the
10 input power to the optical fiber 2 high.

• Relationship between Channel Arrangement and
Characteristic Required for Optical Fiber

Three required characteristics for a DSF
(optical fiber 2) must be taken into consideration when
15 it is tried to achieve optical transmission based on the
WDM method, including 1. the zero-dispersion wavelength
 λ_0 , 2. the zero-dispersion wavelength deviation $\pm \Delta \lambda_0$,
and 3. the dispersion slope (second-order dispersion)
 $dD/d\lambda$ as described hereinabove. Here, the zero-
20 dispersion wavelength deviation $\pm \Delta \lambda_0$ signifies not only
a dispersion involved in production of a DSF but also a
maximum deviation width of the zero-dispersion
wavelength λ_0 in the longitudinal direction of the
optical fiber 2 within the distance L_{r-r} between the
25 regenerative-repeaters 13.

FIG. 20 illustrates a result of measurement of
the FWM production efficiency η when two signal light

1 waves were inputted to an actual DSF and the wavelength
2 λ_2 of one of the two signal light waves was fixed to
3 1.557 nm while the wavelength λ_1 of the other signal
4 light wave was varied. In FIG. 20, the result of
5 measurement is indicated by a solid line interconnecting
6 blank round marks. In the measurement, the optical
7 fiber length was 60 km, and the power of each signal
8 light wave was +4 dBm. Comparison with another result
9 of calculation (indicated by a broken line in FIG. 20)
10 conducted with the zero-dispersion wavelength λ_0 fixed
11 to a fixed value reveals that the measurement values
12 indicated by a solid line in FIG. 20 are distributed
13 over a wider wavelength range. This signifies that the
14 zero-dispersion wavelength λ_0 of the actual DSF exhibits
15 a deviation in the longitudinal direction of the DSF.

16 Taking the foregoing points described above into
17 consideration, in the optical wavelength multiplex
18 transmission method of the seventh embodiment of the
19 present invention, signal light waves of different
20 channels are arranged in such a manner, for example, as
21 illustrated in FIG. 13. It is to be noted that, in the
22 present embodiment, description will be given of the
23 case wherein signal light waves of four channels are
24 wavelength multiplexed and transmitted.

25 In particular, referring to FIG. 13, taking the
zero-dispersion wavelength λ_0 of the optical fiber 2 and
the zero-dispersion wavelength deviation $\pm\Delta\lambda_0$ in the

1 longitudinal direction of the optical fiber 2 into
consideration. signal light waves of four channels to be
multiplexed are arranged at an equal spacing $\Delta\lambda_s$ on the
shorter wavelength side than a short wavelength end λ_0 -
5 $\Delta\lambda_0$ of the range of the zero-dispersion wavelength
deviation of the optical fiber 2.

In this instance, an FWM suppressing guard band
 $\Delta\lambda_g$ is provided on the shorter wavelength side than the
short wavelength end $\lambda_0 - \Delta\lambda_0$ of the zero-dispersion
10 wavelength deviation range of the optical fiber 2, and
signal light waves of four channels (wavelengths λ_1 to
 λ_4 in the channels 1 to 4) are arranged on the further
shorter wavelength side than the wavelength $\lambda_0 - \Delta\lambda_0 -$
 $\Delta\lambda_g$. In the present embodiment, the wavelength λ_1 of
15 the channel 1 is set to the position spaced by $\Delta\lambda_0 + \Delta\lambda_g$
on the shorter wavelength side than the zero-dispersion
wavelength λ_0 of the DSF (optical fiber 2). In other
words, the wavelength $\lambda_0 - \Delta\lambda_0 - \Delta\lambda_g$ is set so as to
coincide with the wavelength λ_1 of the channel 1.

20 Further, in the present embodiment, signal light
waves of four channels are arranged within the
transmissible bandwidth $\Delta\lambda_{SPM-GVD}$ defined by the
allowable dispersion value D_{allow} determined from an
SPM-GVD effect in the optical fiber 2. In particular,
25 as seen from FIG. 13, the transmissible wavelength range
of signal light is a range within $\Delta\lambda_{SPM-GVD} =$
 $|D_{allow}|/(dD/d\lambda)$ on the shorter wavelength side than the

long wavelength end $\lambda_0 + \Delta\lambda_0$ of the zero-dispersion wavelength deviation range of the optical fiber 2. In this instance, in order to allow transmission of four waves and allow the zero-dispersion wavelength deviation $\Delta\lambda_0$ to be set as great as possible, the wavelength $\lambda_{SPM-GVD} (= (\lambda_0 + \Delta\lambda_0) - \Delta\lambda_{SPM-GVD})$ and the wavelength λ_4 of the channel 4 are set so as to coincide with each other.

Further, in the present embodiment, signal light waves of four channels are arranged within a gain band $\Delta\lambda_{EDFA}$ (such a range of 1.550 to 1.560 nm as illustrated, for example, in FIG. 16) of an EDFA (optical amplifier arranged in each in-line repeater 12) connected to the optical fiber 2.

It is to be noted that, though not illustrated in FIG. 13, when the productivity of semiconductor lasers (light sources of signal light waves) and/or the optical wavelength variations of signal light waves caused by the wavelength control accuracy are taken into consideration, the bandwidth $\Delta\lambda_{WDM}$ within which signal light waves of a plurality of channels are arranged is set in an expanded condition in accordance with such variations.

Here, the example of a signal light arrangement illustrated in FIG. 13 is described in more detail by way of an example of numerical values. The relationship between a channel arrangement and characteristics

required for a DSF is described for the case wherein, for example, four signal light waves of the transmission rate 10 Gbps are arranged at an equal distance of the wavelength spacing $\Delta\lambda_s = 2$ nm on the shorter wavelength side than the zero-dispersion wavelength λ_0 of the DSF (optical fiber 2) and the distance $L_{in-line}$ between the in-line repeaters 12 is set to 70 km while the distance L_{reg} between the regenerative-repeaters 13 is set to 280 km.

First, the relationship of the guard band $\Delta\lambda_g$ with which the crosstalk amounts at all of the channels are smaller than -30 dB to the wavelength spacing $\Delta\lambda_s$ when the optical fiber length is 70 km and the input power of each channel is +6 dBm is illustrated in FIG.

21. From FIG. 21, it can be seen that, where the wavelength spacing $\Delta\lambda_s$ is 2 nm (signal light bandwidth $\Delta\lambda_{SDM} = 6$ nm), the guard band $\Delta\lambda_g$ is required to be $\Delta\lambda_g = 3$ nm.

In order to effectively utilize the gain band (1.550 to 1.560 nm) of the EDFA, the wavelength λ_1 of the channel 1 is set to 1.560 nm which is the longer wavelength end of the gain band as seen from FIG. 13. In this instance, the wavelength λ_1 is displaced by $\Delta\lambda_0 + \Delta\lambda_g$ toward the shorter wavelength side from the zero-dispersion wavelength λ_0 of the DSF as described hereinabove.

Further, since the allowable dispersion value

00000000-051000
00000000-051000

5 |D₁₁₀₀|/(dD/dλ) toward the shorter wavelength side from
the wavelength λ₀ + Δλ₀ as described hereinabove, and in
order to allow transmission of all of the four waves and
allow the zero-dispersion wavelength deviation Δλ₀ to be
set as great as possible, the wavelength (λ₀ + Δλ₀) -
0 Δλ_{SPM-GVD} and the wavelength λ₄ of the channel 4 are set
so as to coincide with each other. From those
requirements, the values of Δλ_{SPM-GVD}, Δλ₀ and λ₀ are
defined in the equations given below:

$$\Delta\lambda_0 = (\Delta\lambda_{SPM-GVD} - \Delta\lambda_{WDM} - \Delta\lambda_g)/2 = 1.75 \text{ nm}$$

$$\lambda_0 = \lambda_1 + \Delta\lambda_0 + \Delta\lambda_g = 1.564.75 \text{ nm}$$

25 While the case wherein no optical dispersion compensator is employed has been described with reference to FIG. 13, an alternative case wherein signal light arrangement of different channels is performed

1 using an optical dispersion compensator will be
described subsequently. In particular, the optical
wavelength multiplex transmission method of the seventh
embodiment of the present invention can arrange signal
5 light waves of different channels in such a manner, for
example, as illustrated in FIG. 14 using an optical
dispersion compensator. It is to be noted that
description is given also here of the case wherein
signal light waves of four channels are wavelength
10 multiplexed and transmitted.

In particular, signal light waves of four
channels are first arranged outside a transmissible band
 $\Delta\lambda_{SPM-GVD}$ defined by an allowable dispersion value
 D_{allow} determined from an SPM-GVD effect in the optical
15 fiber 2 as illustrated at an upper half of FIG. 14, and
then the zero-dispersion wavelength λ_0 of the optical
fiber 2 is shifted to λ_0' as illustrated at a lower half
of FIG. 14 using an optical dispersion compensator to
arrange the signal light waves of the four channels
20 apparently in the transmissible band $\Delta\lambda_{SPM-GVD}$.

In this instance, the signal light waves of the
four channels are arranged, before they are shifted by
the optical dispersion compensator, at the equal spacing
 $\Delta\lambda_s$ on the shorter wavelength side than the wavelength
25 $\lambda_0 - \Delta\lambda_0 - \Delta\lambda_s$ and within the gain bandwidth $\Delta\lambda_{EDFA}$ of
the EDFA similarly as in the example of an arrangement
described hereinabove with reference to FIG. 13. It is

5 Then, by shifting the actual zero-dispersion
wavelength λ_0 by $\Delta\lambda_{DC}$ toward the shorter wavelength side
by means of the optical dispersion compensator, the
signal light waves of the four channels are arranged
apparently in the transmissible bandwidth $\Delta\lambda_{SPM-GVD}$ as
0 seen in the lower half of FIG. 14.

20 Further, though not illustrated in FIG. 14,
where an optical dispersion compensator is employed as
described above, taking the dispersion compensation
amount deviation range $\pm\delta\lambda_{DC}$ of the optical dispersion
compensator into consideration, the signal light
25 bandwidth $\Delta\lambda_{WDM}$ is set expanding the same by the
dispersion compensation amount deviation range $\delta\lambda_{DC}$ on
the opposite sides of the longer wavelength side and the

1 shorter wavelength side. Further, for the optical
dispersion compensator, such optical dispersion
compensators, for example, as hereinafter described in
connection with ninth to fifteenth embodiments of the
5 present invention can be employed.

Here, the example of a signal light arrangement
illustrated in FIG. 14 is described using an example of
detailed values. It is to be noted that the case
wherein the zero-dispersion wavelength deviation $\Delta\lambda_0$ of
10 the optical fiber 2 can be set to the maximum using an
optical dispersion compensator having a dispersion value
of the opposite positive or negative sign to that of the
transmission line of a signal band and the dispersion
compensation wavelength shift amount $\Delta\lambda_{DC}$ can be
15 minimized from the points of the size and the optical
loss of the optical dispersion compensator is considered
here. Further, as regards numerical values, it is
assumed here that they are similar to those described
hereinabove with reference to FIG. 13.

20 The zero-dispersion wavelength deviation $\Delta\lambda_0$ is
allowed to be set to the maximum when an area over which
the range of $\Delta\lambda_{SPM-GVD}$ toward the longer wavelength side
from the lower limit of the zero-dispersion wavelength
deviation and the range of $\Delta\lambda_{SPM-GVD}$ toward the shorter
25 wavelength side from the lower limit of the zero-
dispersion wavelength deviation overlap with each other
coincides with the signal light bandwidth $\Delta\lambda_{WDM}$ as seen

336750-00000000

from the lower half of FIG. 14. In short,

$$\begin{aligned}\Delta\lambda_0(\text{max}) &= (2 \cdot \Delta\lambda_{\text{SPM-GVD}} - \Delta\lambda_{\text{WDM}})/2 \\ &= (2 \times 12.5 - 6)/2 = 9.5 \text{ nm}\end{aligned}$$

and in this instance, the apparent zero-dispersion wavelength λ_0' after dispersion compensation is positioned at the center of the signal light bandwidth $\Delta\lambda_{\text{WDM}}$.

Before dispersion compensation, as shown in the upper half of FIG. 14, the wavelength λ_1 of the channel 1 is displaced by $\Delta\lambda_0 + \Delta\lambda_g$ toward the shorter wavelength side from the zero-dispersion wavelength λ_0 from the requirement for FWM suppression. Accordingly,

$$\lambda_0 = \lambda_1 + \Delta\lambda_0 + \Delta\lambda_g = 1.572.5 \text{ nm}$$

and accordingly, $\lambda_0 \pm \Delta\lambda_0 = 1.572.5 \pm 9.5 \text{ nm}$.

In this instance, the dispersion compensation wavelength shift amount $\Delta\lambda_{\text{DC}}$ is $\lambda_0 - \lambda_0'$, and is calculated in the following manner:

$$\begin{aligned}\Delta\lambda_{\text{DC}} &= (2 \cdot \Delta\lambda_0 - \Delta\lambda_{\text{SPM-GVD}}) + \Delta\lambda_g + \Delta\lambda_{\text{WDM}} \\ &= (2 \times 9.5 - 12.5) + 3 + 6 = 15.5 \text{ nm}\end{aligned}$$

Optical dispersion compensators are required to have a higher dispersion, a lower loss and a smaller size, and various types of optical dispersion compensators including the dispersion compensation fiber type, the transversal filter type and the optical resonator type have been proposed. Here, optical dispersion compensators of the optical dispersion compensation type, which will be hereinafter described

in connection with the ninth to fifteenth embodiments of the present invention, are employed.

It is to be noted that, since the example illustrated in FIG. 14 requires an optical dispersion compensator having a positive dispersion value, if, for example, an ordinary single mode fiber (dispersion value $D_{0c} = 18 \text{ ps}/(\text{nm} \cdot \text{km})$) is employed, then the required fiber length L_{0c} is given in the following manner:

$$\begin{aligned} L_{0c} &= (\Delta\lambda_{0c} \cdot dD/d\lambda \cdot L_{R-r.o.p.})/D_{0c} \\ &= (15.5 \times 0.08 \times 280)/18 = 19.3 \text{ km} \end{aligned}$$

While, in the examples of FIGS. 13 and 14 described hereinabove, detailed examples have been described for the cases wherein the zero-dispersion wavelength deviation $\Delta\lambda_0$ has the minimum value and the maximum value, respectively, the relationship of the zero-dispersion wavelength λ_0 and the dispersion compensation wavelength shift amount $\Delta\lambda_{0c}$ to the deviation $\Delta\lambda_0$ where signal light waves are arranged on the shorter wavelength side than the zero-dispersion wavelength λ_0 is illustrated in FIG. 22. In FIG. 22, the relationship where the wavelength spacing $\Delta\lambda_s$ is $\Delta\lambda_s = 2 \text{ nm}$ and the guard band $\Delta\lambda_g$ is $\Delta\lambda_g = 3 \text{ nm}$ is indicated by a solid line. Meanwhile, the relationship where the wavelength spacing $\Delta\lambda_s$ is $\Delta\lambda_s = 3 \text{ nm}$ is indicated by a broken line. In this instance, from FIG. 13, since it is only required that the zero-dispersion wavelength λ_0 and the wavelength λ_1 of the channel 1 do not coincide

with each other. the guard band $\Delta\lambda_g$ is set to $\Delta\lambda_g = 1$ nm.

In this manner, with the optical wavelength multiplex transmission method of the seventh embodiment, signal light waves of different channels can be arranged without being influenced by FWM in an optical amplifier multi-repeater WDM method which makes use of a band in the proximity of the zero-dispersion wavelength λ_0 of the optical fiber 2, and simultaneously, a required characteristic regarding the zero-dispersion wavelength λ_0 of an optical fiber transmission line to be laid can be made definite and a channel arrangement method for signal light and a transmission line designing method in an optical amplifier multi-repeater WDM method can be established.

Particularly, according to the present embodiment, by arranging signal light waves of different channels on the shorter wavelength side than the wavelength $\lambda_0 - \Delta\lambda_0 - \Delta\lambda_g$ taking the zero-dispersion wavelength deviation range and the FWM suppressing guard band into consideration, the zero-dispersion wavelength deviation in the longitudinal direction of the optical fiber 2 is taken into consideration and controlled, and simultaneously, an influence of FWM is suppressed. Consequently, an influence from another channel by crosstalk is suppressed, and a high degree of transmission accuracy can be maintained.

Further, according to the present invention, in addition to the fact that signal light arrangement can be performed taking waveform degradation by an SPM-GVD effect into consideration, the powers of the signal light waves can be made equal and the received characteristics for the signal light waves can be made equal by arranging the signal light waves of the different channels within the gain bandwidth $\Delta\lambda_{\text{EDFA}}$ of the EDFA.

Furthermore, by setting the bandwidth $\Delta\lambda_{\text{WDM}}$, within which signal light waves are to be arranged, in an expanded condition in accordance with optical wavelength variations of the signal light waves of the different channels, the variations of the signal light waves caused by the productivity and/or the wavelength control accuracy of light sources for the signal light waves such as semiconductor lasers are taken into consideration, and where an optical dispersion compensator is employed, by setting the bandwidth $\Delta\lambda_{\text{WDM}}$, within which the signal light waves are to be arranged, expanding the same by the dispersion compensation amount deviation range $\delta\lambda_{\text{DC}}$ of the optical dispersion compensator on the opposite sides of the longer wavelength side and the shorter wavelength side, also the dispersion compensation amount deviation of the optical dispersion compensator is taken into consideration. Consequently, optical transmission of

higher reliability can be achieved.

It is to be noted that, while, in the seventh embodiment described above, the case wherein signal light waves of four channels are to be arranged is described above, the present invention is not limited to this.

H. Eighth Embodiment

Subsequently, an optical wavelength multiplex transmission method of an eighth preferred embodiment of the present invention. FIG. 23 illustrates a signal light arrangement of a plurality of channels of the optical wavelength multiplex transmission method while FIG. 24 illustrates a modification to the signal light arrangement illustrated in FIG. 23. and FIG. 25 illustrates the relationship of the zero-dispersion wavelength and the dispersion compensation amount to the zero-dispersion wavelength deviation in the optical wavelength multiplex transmission method. It is to be noted that also the optical wavelength multiplex transmission method of the eighth embodiment is applied to a system similar to the regenerative-repeater system or optical transmission system described hereinabove with reference to FIG. 15, and overlapping description of the same will be omitted herein to avoid redundancy.

While, in the seventh embodiment described above, description has been given of the case wherein signal light waves of different channels are arranged on

1 the shorter wavelength side than the zero-dispersion
wavelength λ_0 of the optical fiber 2. in the eighth
embodiment. signal light waves of different channels are
arranged on the longer wavelength side than the zero-
5 dispersion wavelength λ_0 of the optical fiber 2. Then,
after the wavelength λ_1 of the channel 1 is set to the
shorter wavelength end 1.550 nm of the gain bandwidth of
the EDFA, the relationship between the channel
arrangement and characteristics required for the DSF
10 (optical fiber 2) are determined by the quite same means
as that of the seventh embodiment described hereinabove
with reference to FIG. 13.

In particular, taking the zero-dispersion
wavelength λ_0 of the optical fiber 2 and the zero-
15 dispersion wavelength deviation $\pm\Delta\lambda_0$ in the longitudinal
direction of the optical fiber 2 into consideration,
signal light waves of fourth channels to be multiplexed
are arranged at an equal spacing $\Delta\lambda_s$ on the longer
wavelength side than the longer wavelength end $\lambda_0 + \Delta\lambda_0$
20 of the zero-dispersion wavelength deviation range of the
optical fiber 2 as illustrated in FIG. 23.

In this instance, an FWM suppressing guard band
 $\Delta\lambda_g$ is provided on the longer wavelength side than the
longer wavelength end $\lambda_0 + \Delta\lambda_0$ of the zero-dispersion
25 wavelength deviation range of the optical fiber 2, and
the signal light waves of the four channels (for the
channels 1 to 4 of the wavelengths λ_1 to λ_4) are

arranged on the further longer wavelength side than the wavelength $\lambda_0 + \Delta\lambda_0 + \Delta\lambda_g$. In the present embodiment, the wavelength λ_1 of the channel 1 is set at the position displaced by $\Delta\lambda_0 + \Delta\lambda_g$ toward the longer wavelength side from the zero-dispersion wavelength λ_0 of the DSF (optical fiber 2), that is, the wavelength $\lambda_0 + \Delta\lambda_0 + \Delta\lambda_g$ is set so as to coincide with the wavelength λ_1 of the channel 1.

Further, in the present embodiment, signal light waves of four channels are arranged in a transmissible band $\Delta\lambda_{SPM-GVD}$ defined by an allowable dispersion value D_{allow} determined from an SPM-GVD in the optical fiber 2. In particular, as illustrated in FIG. 23, the transmissible signal light wavelength range is a range within $\Delta\lambda_{SPM-GVD} = |D_{allow}| / (dD/d\lambda)$ displaced toward the longer wavelength side from the shorter wavelength end $\lambda_0 - \Delta\lambda_0$ of the zero-dispersion wavelength deviation range of the optical fiber 2. In this instance, in order to allow the four waves to be transmitted and allow the zero-dispersion wavelength deviation $\Delta\lambda_0$ to be set as great as possible, the wavelength $\lambda_{SPM-GVD}$ ($= (\lambda_0 - \Delta\lambda_0) + \Delta\lambda_{SPM-GVD}$) and the wavelength λ_4 of the channel 4 are set so as to coincide with each other.

Further, in the present embodiment, the signal light waves of the four channels are arranged within a gain bandwidth $\Delta\lambda_{EDFA}$ (for example, such a range of 1.550 to 1.560 nm as shown in FIG. 16) of an EDFA

1 connected to the optical fiber 2.

It is to be noted that, though not illustrated
in FIG. 23, also in the present embodiment, when the
productivity of semiconductor lasers (light sources of
5 signal light waves) and/or the optical wavelength
variations of the signal light waves caused by the
wavelength control accuracy are taken into
consideration, the bandwidth $\Delta\lambda_{\text{WDM}}$ within which signal
light waves of a plurality of channels are to be
10 arranged is set in an expanded condition in accordance
with such variations.

By the way, while the case wherein an optical
dispersion compensator is not employed is described
above with reference to FIG. 23, another case wherein
15 signal light arrangement of different channels is
performed using an optical dispersion compensator will
be described subsequently. In other words, with the
optical wavelength multiplex transmission method of the
eighth embodiment of the present invention, signal light
20 waves of different channels can be arranged, for
example, in such a manner as illustrated in FIG. 24 by
using an optical dispersion compensator.

In particular, signal light waves of four
channels are first arranged outside a transmissible band
25 $\Delta\lambda_{\text{SPM-GVD}}$ defined by an allowable dispersion value
 $\Delta\lambda_{\text{allow}}$ determined by an SPM-GVD effect in the optical
fiber 2 as illustrated in the upper half of FIG. 24, and

00000000-051900

then the zero-dispersion wavelength λ_0 of the optical fiber 2 is shifted to λ_0' using an optical dispersion compensator as illustrated in the lower half of FIG. 24 to arrange the signal light waves of the four channels apparently within the transmissible band $\Delta\lambda_{SPM-GVD}$.

In this instance, the signal light waves of the four channels are arranged, before shifting by the optical dispersion compensator is performed, at an equal spacing $\Delta\lambda_s$ on the longer wavelength side than the wavelength $\lambda_0 + \Delta\lambda_0 + \Delta\lambda_g$ and within the gain bandwidth $\Delta\lambda_{EDFA}$ of the EDFA similarly as in the example of an arrangement described hereinabove with reference to FIG. 23. It is to be noted that the wavelength λ_1 of the channel 1 is set so as to coincide with the wavelength $\lambda_0 + \Delta\lambda_0 + \Delta\lambda_g$ displaced by $\Delta\lambda_0 + \Delta\lambda_g$ toward the longer wavelength side from the zero-dispersion wavelength λ_0 .

Then, the actual zero-dispersion wavelength λ_0 is shifted by $\Delta\lambda_{DC}$ ($= \lambda_0' - \lambda_0$) toward the longer wavelength side by means of the optical dispersion compensator thereby to apparently arrange the signal light waves of the four channels within the transmissible band $\Delta\lambda_{SPM-GVD}$.

It is to be noted that also FIG. 24 illustrates the case wherein, as described hereinabove in connection with the seventh embodiment with reference to FIG. 14, an area over which the range of $\Delta\lambda_{SPM-GVD}$ displaced toward the longer wavelength side from the lower limit

1 of the zero-dispersion wavelength deviation and the
range of $\Delta\lambda_{spn-gvd}$ displaced toward the shorter
wavelength side from the lower limit of the zero-
dispersion wavelength deviation overlap with each other
5 is made coincide with the signal light bandwidth $\Delta\lambda_{wdm}$
so that the zero-dispersion wavelength deviation $\Delta\lambda_0$ is
allowed to be set to the maximum as described
hereinabove in connection with the seventh embodiment
with reference to FIG. 14.

10 Further, though not illustrated in FIG. 24, when
the productivity of semiconductor lasers (light sources
of the signal light waves) and/or the optical wavelength
variations of the signal light waves caused by the
wavelength control accuracy are taken into
15 consideration, the bandwidth $\Delta\lambda_{wdm}$ within which signal
light waves of a plurality of channels are to be
arranged is set in an expanded condition in accordance
with such variations.

20 Further, though not illustrated in FIG. 24,
where an optical dispersion compensator is employed as
described above, taking the dispersion compensation
amount deviation range $\pm\delta\lambda_{dc}$ of the optical dispersion
compensator into consideration, the signal light
bandwidth $\Delta\lambda_{wdm}$ is set expanding the same by the
25 dispersion compensation amount deviation range $\delta\lambda_{dc}$ on
the opposite sides of the longer wavelength side and the
shorter wavelength side. Further, for the optical

BB6T50-60603060

1 dispersion compensator, such optical dispersion
compensators, for example, as hereinafter described in
connection with ninth to fifteenth embodiments of the
present invention can be employed.

5 While, in the examples of FIGS. 23 and 24
described hereinabove, the cases wherein the zero-
dispersion wavelength deviation $\Delta\lambda_0$ has the minimum
value and the maximum value, respectively, have been
described, the relationship of the zero-dispersion
10 wavelength λ_0 and the dispersion compensation wavelength
shift amount $\Delta\lambda_{bc}$ to the deviation $\Delta\lambda_0$ where signal
light waves are arranged on the longer wavelength side
than the zero-dispersion wavelength λ_0 is illustrated in
FIG. 25. Also in FIG. 25, similar numerical values to
15 those described hereinabove in connection with the
seventh embodiment with reference to FIG. 22 are
applied. However, in FIG. 25, the slope of the zero-
dispersion wavelength λ_0 relative to the deviation $\Delta\lambda_0$
is set opposite to that illustrated in FIG. 22 in order
20 to arrange the signal light waves on the longer
wavelength side than the zero-dispersion wavelength λ_0 .

In this manner, similar advantages to those
described hereinabove in connection with the seventh
embodiment can be achieved by the optical wavelength
25 multiplex transmission method of the eighth embodiment.

It is to be noted that, while, in the eighth
embodiment described above, the case wherein the signal

1 light waves of the four channels are to be arranged has
been described. the present invention is not limited to
this. and the signal light waves of the channels can be
arranged on the opposite sides of the zero-dispersion
5 wavelength λ_0 . In this instance, when optical
dispersion compensation is involved, different optical
dispersion compensators of the opposite positive and
negative signs must necessarily be used for the channels
on the shorter wavelength side and the longer wavelength
10 side of the zero-dispersion wavelength λ_0 .

I. Ninth Embodiment

Subsequently, an optical dispersion compensation
method as a ninth preferred embodiment of the present
invention will be described. FIG. 26 shows, in block
15 diagram, an optical dispersion compensation system to
which the optical dispersion compensation method is
applied. Referring to FIG. 26, the optical dispersion
compensation system shown is denoted at 20 and includes
a transmitter 21 for converting an electric signal into
20 an optical signal and transmitting the optical signal,
and a plurality of repeaters 22 inserted in an optical
transmission line (optical fiber 2). Such an in-line
repeater or a regenerative-repeater as described
hereinabove may be employed for the repeaters 22.

25 The optical dispersion compensation system 20
further includes a receiver 23 for converting a received
optical signal into an electric signal. The transmitter

1 21 and the receiver 23 are interconnected by way of the
optical fiber 2 with the repeaters 22 interposed in the
optical fiber 2. In the optical transmission system 20,
signal light from the transmitter 21 is transmitted to
5 the receiver 23 by way of the repeaters 22 and the
optical fiber 2.

The optical dispersion compensation system 20
further includes two kinds of optical dispersion
compensator units including an optical dispersion
10 compensator unit 24A having a positive dispersion amount
+B and another optical dispersion compensator unit 24B
having a negative dispersion amount -B. The two kinds
of optical dispersion compensator units 24A and 24B are
prepared in advance and are interposed in the optical
15 transmission system 20, that is, at any location of the
optical fiber 2, the transmitter 21, the repeaters 22
and the receiver 23.

By the way, where the optical transmission
system 20 is such an optical amplifier regenerative-
20 repeater system as described hereinabove with reference
to FIG. 15, since the allowable dispersion value
decreases as the regenerative-repeater span increases as
described hereinabove with reference to FIG. 19, an
optical dispersion compensator for restraining the
25 arrangement positions of the channels (signal light)
within an allowable dispersion range for the arrangement
positions is essentially required.

1 Further, while, in the first to eighth
embodiments described hereinabove, the zero-dispersion
wavelength of the optical fiber 2 and the signal light
wavelength are separated from each other in order to
5 eliminate otherwise possible crosstalk by FWM in the WDM
method which makes use of a band in the proximity of the
zero-dispersion wavelength of the optical fiber 2,
dispersion compensation by the corresponding amount
(refer particularly to the examples of FIGS. 14 and 24
10 in the seventh and eighth embodiments) is required.
Such dispersion compensation is required also for one-
wave transmission or SMF transmission.

Particularly in the case of an optical
communication system on land, since the repeater span is
15 not fixed and besides the zero-dispersion wavelength of
an actual optical fiber exhibits a deviation in the
longitudinal direction, it is difficult to set the
dispersion amounts of different repeater sections equal
to each other. Therefore, when a signal light
20 wavelength is set in the proximity of the zero-
dispersion wavelength of the DSF (optical fiber 2),
there is even the possibility that the positive or
negative sign of the dispersion amount may be different
among different repeater sections.

25 Thus, in the present ninth embodiment, in order
to compensate for the dispersion amount of the optical
transmission system 20, the two kinds of optical

10

15

20

25

1 system is built up can be realized.

Here, an example of detailed numerical values of
the ninth embodiment will be described. If it is
assumed that the transmission rate is 10 Gbps; the in-
5 line repeater span L_{line} is 70 km; the variation of
the optical output of each optical amplifier is ± 2 dB,
from FIG. 19, the maximum regenerative-repeater span is
280 km at the allowable dispersion value $D_{\text{allow}} = \pm 1$
ps/(nm·km), and accordingly, the dispersion compensation
10 of ± 280 ps/nm is required for the dispersion amount of
signal light after transmission of 280 km. Therefore,
where the transmission line dispersion amount is, for
example, $+1.200$ ps/nm, when the optical dispersion
compensator units 24A and 24B of the dispersion amounts
15 $+1.000$ ps/nm and -1.000 ps/nm are prepared, if the
optical dispersion compensator unit 24B of the
dispersion amount -1.000 ps/nm is inserted into the
transmission line, then the total dispersion amount is
 $+200$ ps/nm, and therefore, transmission is possible.

20 J. Tenth Embodiment

Subsequently, an optical dispersion compensation
method of a tenth preferred embodiment of the present
invention will be described. FIG. 27 shows, in block
diagram, an optical dispersion compensation apparatus to
25 which the optical dispersion compensation method is
applied. In FIG. 27, like elements are denoted by like
reference characters to those of FIG. 26, and

1 overlapping description thereof is omitted herein to
avoid redundancy.

While, in the ninth embodiment described above,
the two kinds of optical dispersion compensator units
5 having the positive dispersion amount $+B$ and the
negative dispersion amount $-B$ are prepared in advance,
in the present tenth embodiment, a plurality of kinds of
optical dispersion compensators 25A and 25B having
different dispersion amounts having different positive
10 and negative signs are prepared in advance.

Here, two kinds of optical dispersion compensator units 25A and 25B having dispersion amounts B1 and B2 are prepared each by a plural number, and an optical dispersion compensator unit 25 which is constituted from a combination of such optical dispersion compensation units 25A and 25B is inserted into the optical transmission system 20, that is, at any portion of the optical fiber 2, the transmitter 21, the repeaters 22 and the receiver 23.

20 Further, in the present embodiment, at a cite at
which an optical communication system is to be
installed, the two kinds of optical dispersion
compensator units 25A and 25B are inserted into the
optical transmission system 20 changing the number and
25 the combination of units to be installed, and the
transmission characteristic, particularly the code error
rate, of the optical transmission system 20 is measured.

1 Then, an optical dispersion compensator unit 25 of the
number and the combination of units which provide a good
transmission characteristic (in FIG. 27, the combination
of three optical dispersion compensator units 25A and
5 one optical dispersion compensator unit 25B) is
selectively determined from the two kinds of optical
dispersion compensator units 25A and 25B and
incorporated into the optical transmission system 20.

10 Consequently, even when the zero-dispersion
wavelength deviation is not known or when the zero-
dispersion and the signal light wavelength are displaced
by a great amount from each other, the dispersion amount
of the optical transmission system 20 can be compensated
for readily and optimally.

15 In contrast, when the dispersion amount of the
optical transmission system 20 can be measured, the
dispersion amount is measured first, and then an optical
dispersion compensator unit 25 of the installation
number and the combination of units with which the
20 dispersion value of signal light falls within a
transmissible dispersion value range is selectively
determined from the two kinds of optical dispersion
compensator units 25A and 25B and incorporated into the
optical transmission system 20. Consequently, the
25 dispersion amount of the optical transmission system 20
can be compensated for so that it can be accommodated
into the allowable dispersion value range with

1

5

15

20

25

1 into the transmission line. then the total dispersion
amount is +200 ps/nm. which allows transmission.

K. Eleventh Embodiment

5 Subsequently, an optical dispersion compensation
method of an eleventh preferred embodiment of the
present invention will be described. FIG. 28 shows, in
block diagram, an optical dispersion compensation
apparatus to which the optical dispersion compensation
method is applied, and FIGS. 29 and 30 show different
10 modifications to the optical dispersion compensation
apparatus. It is to be noted that, while, in the ninth
and tenth embodiments described above, description has
been given only of transmission of one signal light
wave, in the present embodiment, description will be
15 given of the case wherein signal light waves
(wavelengths λ_1 to λ_4) of four channels are wavelength
multiplexed and transmitted.

As seen from FIG. 28, also in the present
embodiment, an optical transmission system 20 is
20 constituted from a transmitter 21, a plurality of
repeaters 22 and a receiver 23 interconnected by an
optical fiber 2. However, in the present eleventh
embodiment, the transmitter 21 is constructed so as to
first convert electric signals of different channels
25 into signal light waves having different wavelengths or
frequencies from one another and then multiplex the
signal light waves by optical wavelength multiplexing.

10 Meanwhile, the receiver 23 demultiplexes
multiplexed signal light transmitted thereto from the
transmitter 21 by way of the optical fiber 2 and the
repeaters 22 and converts signal light waves obtained by
such demultiplexing individually into electric signals.
15 To this end, the receiver 23 includes an optical
demultiplexing section 23a for demultiplexing and
distributing multiplexed signal light into different
channels, and a plurality of opto-electric conversion
sections (O/E1 to O/E4) 23b provided individually for
20 the channels for converting signal light waves of the
channels distributed thereto from the optical
demultiplexing section 23a into electric signals.

Further, in the present embodiment, optical dispersion compensator units 25 are interposed between the electro-optical conversion sections 21a and the optical multiplexing section 21b of the transmitter 21. In particular, a suitable number and combination of

1 optical dispersion compensator units 25A and 25B are
provided for each of signal light waves of wavelengths
2 λ_1 to λ_4 before wavelength multiplexing.

5 In the arrangement shown in FIG. 28, for the
channel of the wavelength λ_1 , only one optical
dispersion compensator unit 25A of the dispersion amount
B1 is provided; for the channel of the wavelength λ_2 ,
one optical dispersion compensator unit 25A of the
dispersion amount B1 and one optical dispersion
10 compensator unit 25B of the dispersion amount B2 are
provided; for the channel of the wavelength λ_3 , one
optical dispersion compensator unit 25A of the
dispersion amount B1 and two optical dispersion
compensator units 25B of the dispersion amount B2 are
15 provided; and for the channel of the wavelength λ_4 , one
optical dispersion compensator unit 25A of the
dispersion amount B1 and three optical dispersion
compensator units 25B of the dispersion amount B2 are
provided.

20 In this instance, when the installation number
and the combination of the optical dispersion
compensator units 25A and 25B arranged for the different
channels are to be selected, as described hereinabove in
the ninth and tenth embodiments, those which provide
25 good transmission characteristics for the individual
channels may be selected by trial and error or, when the
dispersion value of the optical transmission system 20

5 While the arrangement wherein the optical
dispersion compensator units 25 are provided in the
transmitter 21 are shown in FIG. 28, such optical
dispersion compensator units 25 may be provided
alternatively in each repeater 22 or the receiver 23 as
0 seen in FIG. 29 or 30.

As shown in FIG. 29, where the optical dispersion compensator units 25 are provided in each repeater 22, the repeater 22 includes, in addition to an optical amplifier 22a constituting the repeater 22, an optical demultiplexing section 22b provided at a next stage to the optical amplifier 22a for demultiplexing signal light amplified by the optical amplifier 22a into individual signal light waves of different wavelengths λ_1 to λ_4 by wavelength demultiplexing, an optical dispersion compensator unit 25 provided for each of the channels of signal light waves of the wavelengths λ_1 to λ_4 demultiplexed by the optical demultiplexing section 22b and including a suitable installation number and a suitable combination of optical dispersion compensator units 25A and 25B, and an optical multiplexing section 22c for multiplexing signal light waves of the channels dispersion compensated for by the optical dispersion

1 compensator units 25 back into signal light by
wavelength multiplexing and sending out the thus
multiplexed signal light into a transmission line. It
is to be noted that the optical demultiplexing section
5 22b, the optical dispersion compensator units 25 and the
optical multiplexing section 22c may be provided
otherwise at a preceding stage to the optical amplifier
22a.

On the other hand, where the optical dispersion
10 compensator units 25 are to be provided in the receiver
23, as shown in FIG. 30, they are interposed between the
optical demultiplexing section 23a and the opto-electric
conversion sections 23b of the receiver 23. In
particular, a suitable installation number and a
15 suitable combination of optical dispersion compensator
units 25A and 25B are provided for each of the signal
light waves of the wavelengths λ_1 to λ_n after wavelength
demultiplexing.

In this manner, with the optical dispersion
20 compensation method of the eleventh embodiment, also
where the optical transmission system 20 performs
optical wavelength multiplex transmission to multiplex
and transmit signal light waves of different
wavelengths, similar advantages to those described
25 hereinabove in connection with the ninth and tenth
embodiments can be attained by providing a suitable
installation number and a suitable combination of

1 optical dispersion compensator units 25A and 25B for
each wavelength.

It is to be noted that, while the embodiment
described above involves four channels of signal light
5 waves to be multiplexed and two kinds of optical
dispersion compensator units prepared in advance for
dispersion compensation for the individual channels, the
present invention is not limited to this.

L. Twelfth Embodiment

10 Subsequently, an optical dispersion compensation
method of a twelfth preferred embodiment of the present
invention will be described. FIG. 31 shows, in block
diagram, an optical dispersion compensation apparatus to
which the optical dispersion compensation method is
15 applied, and FIGS. 32 and 33 show different
modifications to the optical dispersion compensation
apparatus. It is to be noted that like reference
characters denote like elements to those described
hereinabove, and overlapping description thereof is
20 omitted herein to avoid redundancy.

While, in the eleventh embodiment described
above, description has been given of the case wherein a
suitable installation number and a suitable combination
of optical dispersion compensator units 25A and 25B are
25 provided for each wavelength, in the present twelfth
embodiment, a suitable installation number and a
suitable combination of optical dispersion compensator

1 units 25A and 25B are provided in the optical
transmission system 20 for each channel group including
a plurality of signal light waves (two signal light
waves in the present embodiment).

5 In particular, FIGS. 31 to 33 illustrate
different arrangements wherein optical dispersion
compensator units 25 are provided in the transmitter 21,
each of the repeaters 22 and the receiver 23,

10 respectively. Where the optical dispersion compensator
units 25 are provided in the transmitter 21 as shown in
FIG. 31, the optical multiplexing section 21b of the
transmitter 21 described hereinabove includes an optical
multiplexing section 21c for multiplexing signal light
waves of the wavelengths λ_1 and λ_2 from the electro-
15 optical conversion section 21a, another optical
multiplexing section 21d for multiplexing signal light
waves of the wavelengths λ_3 and λ_4 from the electro-
optical conversion section 21a, and a further optical
multiplexing section 21e for multiplexing two signal
20 light beams multiplexed by the optical multiplexing
sections 21c and 21d.

An optical dispersion compensator unit 25 is
interposed between each of the multiplexing sections 21c
and 21d and the optical multiplexing section 21e. In
25 other words, a suitable installation number and a
suitable combination of optical dispersion compensator
units 25A and 25B are provided for each of channel

1 groups each including two signal light waves.

For example, in the arrangement shown in FIG.
31, for the channel group of the wavelengths λ_1 and λ_2 ,
only one optical dispersion compensator unit 25A of the
5 dispersion amount B1 is provided; and for the channel
group of the wavelengths λ_3 and λ_4 , one optical
dispersion compensator unit 25A of the dispersion amount
B1 and one optical dispersion compensator unit 25B of
the dispersion amount B2 are provided.

10 In this instance, when the installation number
and the combination of the optical dispersion
compensator units 25A and 25B to be arranged for the
different channels are to be selected, as described
hereinabove in the ninth and tenth embodiments, those
15 which provide good transmission characteristics for the
individual channels may be selected by trial and error
or, when the dispersion amount of the optical
transmission system 20 can be measured, those with which
the dispersion values of signal light waves fall within
20 a transmissible dispersion value range may be selected
in accordance with a result of the measurement.

Meanwhile, where the optical dispersion
compensator units 25 are provided in each repeater 22 as
shown in FIG. 32, the repeater 22 includes, in addition
25 to the optical amplifier 22a constituting the repeater
22, an optical demultiplexing section 22d provided at a
next stage to the optical amplifier 22a for

On the other hand, where the optical dispersion compensator units 25 are to be provided in the receiver 23, as shown in FIG. 33, the optical demultiplexing section 23a of the receiver 23 described above includes an optical demultiplexer 23c for demultiplexing received signal light into a channel group of the wavelengths λ_1 and λ_2 and another channel group of the wavelengths λ_3 and λ_4 , another optical demultiplexing section 23d for

demultiplexing the channel group of the wavelengths λ_1 and λ_2 into signal light waves of the wavelengths λ_1 and λ_2 , and a further optical demultiplexing section 23e for demultiplexing the channel group of the wavelengths λ_3 and λ_4 into signal light waves of the wavelengths λ_3 and λ_4 .

Further, an optical dispersion compensator unit 25 is interposed between the optical demultiplexing section 23c and each of the optical demultiplexing sections 23d and 23e. In particular, a suitable installation number and a suitable combination of optical dispersion compensator units 25A and 25B are provided for each of the channel groups each including two signal light waves.

In this manner, with the optical dispersion compensation method of the twelfth embodiment, also where the optical transmission system 20 performs optical wavelength multiplex transmission to multiplex and transmit signal light waves of different wavelengths, similar advantages to those described hereinabove in connection with the ninth and tenth embodiments can be attained by providing a suitable installation number and a suitable combination of optical dispersion compensator units 25A and 25B for each channel group.

It is to be noted that, while the embodiment described above involves four channels of signal light

1 waves to be multiplexed and two kinds of optical
dispersion compensator units prepared in advance for
dispersion compensation for the individual channels and
besides involves separation of the channels into two
5 channel groups. the present invention is not limited to
this.

M. Thirteenth Embodiment

Subsequently, an optical dispersion compensation
method of a thirteenth preferred embodiment of the
10 present invention will be described. FIG. 34 shows, in
block diagram, an optical dispersion compensation
apparatus to which the optical dispersion compensation
method is applied, and FIGS. 35 and 36 show different
modifications to the optical dispersion compensation
15 apparatus. It is to be noted that like reference
characters denote like elements to those described
hereinabove, and overlapping description thereof is
omitted herein to avoid redundancy.

While, in the eleventh or twelfth embodiment
20 described above, description has been given of the case
wherein a suitable installation number and a suitable
combination of optical dispersion compensator units 25A
and 25B are provided for each wavelength or for each
channel group. in the present thirteenth embodiment, a
25 suitable installation number and a suitable combination
of optical dispersion compensator units 25A and 25B are
provided in the optical transmission system 20 for all

1

5

20

25

1 the dispersion values of signal light waves fall within a transmissible dispersion value range may be selected in accordance with a result of the measurement.

Meanwhile, where the optical dispersion compensator unit 25 is provided in each repeater 22 as shown in FIG. 35, it is located at a next stage to the optical amplifier 22a constituting the repeater 22 and includes a suitable installation number and a suitable combination of optical dispersion compensator units 25A and 25B. It is to be noted that the optical dispersion compensator unit 25 may be provided otherwise at a preceding stage to the optical amplifier 22a.

On the other hand, where the optical dispersion compensator unit 25 is to be provided in the receiver 23, as shown in FIG. 36, it is located at a preceding stage to the optical demultiplexing section 23a of the receiver 23 and includes a suitable installation number and a suitable combination of optical dispersion compensator units 25A and 25B.

20 In this manner, with the optical dispersion compensation method of the thirteenth embodiment, also where the optical transmission system 20 performs optical wavelength multiplex transmission to multiplex and transmit signal light waves of different
25 wavelengths, similar advantages to those described hereinabove in connection with the ninth and tenth embodiments can be attained by providing a suitable

1 installation number and a suitable combination of
optical dispersion compensator units 25A and 25B for all
of signal light waves of the channels.

5 It is to be noted that, while the embodiment
described above involves four channels of signal light
waves to be multiplexed and two kinds of optical
dispersion compensator units prepared in advance for
dispersion compensation for the individual channels, the
present invention is not limited to this.

10 Further, in the tenth to thirteenth embodiments
described above, it is important to design the
dispersion values of the involved optical dispersion
compensator units taking the wavelength spacing between
the channels and the dispersion slope $dD/d\lambda$ of the
15 transmission line into consideration and reduce the
number of types of optical dispersion compensator units
as small as possible.

N. Fourteenth Embodiment

20 Subsequently, an optical dispersion compensation
method of a fourteenth preferred embodiment of the
present invention will be described. FIG. 37 shows, in
block diagram, an optical dispersion compensation
apparatus to which the optical dispersion compensation
method is applied, and FIGS. 38(a) and 38(b) show a
25 modification to the optical dispersion compensation
apparatus while FIG. 39 show another modification to the
optical dispersion compensation apparatus and FIG. 40

1 shows an example of the construction of a packet based
on the modified optical dispersion compensation
apparatus of FIG. 39. It is to be noted that like
reference characters denote like elements to those
5 described hereinabove, and overlapping description
thereof is omitted herein to avoid redundancy.

While, in the ninth to thirteenth embodiments
described above, description has been given of the
arrangement means for the optical dispersion compensator
10 units 24A, 24B, 25, 25A and 25B, in the present
fourteenth embodiment, examples of a detailed
construction and insertion installation means of the
optical dispersion compensator units 25, 25A and 25B
themselves will be described.

15 For example, as shown in FIG. 37, an optical
amplifier 26 is additionally provided at a preceding
stage or a next stage to each of optical dispersion
compensator units 25A and 25B constituting an optical
dispersion compensator unit 25 for compensating the
20 optical loss by the optical dispersion compensator unit
25A or 25B.

By the way, various types of optical dispersion
compensators have been proposed so far including the
dispersion compensating fiber type, the transversal
25 filter type and the optical resonator type. While
dispersion compensation fibers having a dispersion value
higher than $-100 \text{ ps}/(\text{nm} \cdot \text{km})$ are manufactured at present

1 by contriving the shape of the core. with such
dispersion compensation fibers. the optical loss is high
although a dispersion compensation amount can be
adjusted readily by the length of the fiber.

5 Thus, where the optical dispersion compensator
units 25A and 25B are integrated with an optical
amplifier 26 such as an EDFA as in the fourteenth
embodiment. the optical loss of the dispersion
compensation fiber can be compensated for.

10 It is to be noted that, while an optical
amplifier 26 is additionally provided for each optical
dispersion compensator unit 25A or 25B in FIG. 37. only
one optical amplifier 26 may otherwise be provided for
each group (optical dispersion compensation unit 25) of
15 optical dispersion compensator units 25A and 25B as
shown in FIG. 38(a) or 38(b).

20 Alternatively, a pair of optical amplifiers 26A
and 26B are additionally provided at both of a preceding
stage and a next stage to each group (optical dispersion
compensator unit 25) of optical dispersion compensator
units 25A and 25B as shown in FIG. 39.

25 Where only one amplifier is provided, not only a
high gain sufficient to compensate for both of the
transmission line loss and the optical loss at the
optical dispersion compensator unit 25 is required, but
where the optical dispersion compensator unit 25 having
a high optical loss is located at a preceding stage to

866T50-60608050

the optical amplifier 26, this makes a cause to degrade the NF significantly. This must be eliminated particularly where an optical dispersion compensator unit 25 is inserted in a 1R repeater in an optical amplifier multi-repeater system.

Therefore, where such a construction as shown in FIG. 39 wherein the two optical amplifiers 26A and 26B are provided on the opposite front and rear ends of the optical dispersion compensator unit 25 is employed, the NF of the entire 1R repeater can be reduced low by minimizing the NF of the optical amplifier at the preceding stage, and a sufficient gain can be assured by means of the two stages of optical amplifiers 26A and 26B.

Incorporation of such an optical dispersion compensator unit 25 as described above into the transmitter 21, each of the repeaters 22 or the receiver 23 is performed, for example, in the following manner. A space sufficient to allow insertion of an optical dispersion compensator unit 25 therein is assured in advance in each of the transmitter 21, the repeaters 22 and the receiver 23, and after installation of the system, optimum optical dispersion compensator units 25 conforming to the transmission line (optical transmission system 20) are additionally inserted into the spaces to incorporate the optical dispersion compensators 25 into the optical transmission system 20.

1

10

25

1 readily in units of a package. Consequently, the
dispersion compensation amount can be varied readily.

0. Fifteenth Embodiment

5 Subsequently, an optical dispersion compensation
method of a fifteenth preferred embodiment of the
present invention will be described. FIG. 41 shows, in
block diagram, an optical dispersion compensation
apparatus to which the optical dispersion compensation
method is applied, and FIGS. 42 and 43 show different
10 modifications to the optical dispersion compensation
apparatus. It is to be noted that like reference
characters denote like elements to those described
hereinabove, and overlapping description thereof is
omitted herein to avoid redundancy.

15 In the fifteenth embodiment, such an optical
dispersion compensator unit 32 is built in each of the
transmitter 21, the repeaters 22 and the receiver 23
which constitute the optical transmission system 20.

20 Referring to FIG. 41, the optical dispersion
compensator unit 32 includes three stages of optical
dispersion compensator units 25A to 25D of a plurality
of different kinds (four kinds having dispersion amounts
B1 to B4 in the arrangement shown in FIG. 41) having
different dispersion amounts having different positive
25 and negative signs, and switches (switching means) 29A
to 29C connected to the three stages of optical
dispersion compensator units 25A to 25D for switching

1 the selective combination of the optical dispersion
compensator units 25A to 25D. When each of the switches
29A to 29C is operated for switching, one of the four
kinds of optical dispersion compensator units 25A to 25D
5 of the corresponding stage is selected, and
consequently, by operation of the switches 29A to 29C, a
suitable combination of three optical dispersion
compensator units 25A to 25D can be selectively
incorporated into the optical transmission system 20.

10 It is to be noted that each of the switches 29A
to 29C may be means for wiring any of the optical
dispersion compensator units 25A to 25D by means of an
optical fiber (mechanical connection or mechanical
switch) or means for selecting a connection route by
15 means of an optical switch. The optical switch may be
an optical waveguide switch or a spatial change-over
switch.

Further, as means for changing over each of the
switches 29A to 29C, means for modifying the wiring
20 system of the optical fiber or switching the optical
switch on/off simply by a personal operation from the
outside or means for automatically performing such
changing over operation in response to an electric or
optical control signal from the outside may be applied.

25 Subsequently, detailed adaptations of a
switching operation of the switches 29A to 29C in
response to a control signal from the outside to select

1

۱۰

10

15

25

[illegible]

5
10
15
20
25

In this manner, with the optical dispersion compensation method of the fifteenth embodiment, since a plurality of kinds of optical dispersion compensator units 25A to 25D are built in advance in each of the transmitter 21, the repeaters 22 and the receiver 23 of the optical transmission system 20 in such a connected condition that the combination of optical dispersion compensator units 25A to 25D can be selectively switched by way of the switches 29A to 29C, a suitable combination of optical dispersion compensator units 25A to 25D is selected from within the optical dispersion compensator units 25A to 25D by operating the switches 29A to 29C. Particularly where the construction shown in FIG. 43 is employed, the combination of optical dispersion compensator units 25A to 25D can be

N

5

15

25